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ORIGINAL RESEARCH

INVESTIGATION OF OPTIMAL LUMBAR SPINE POSTURE DURING A SIMULATED LANDING TASK IN ELITE GYMNASTS

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ABSTRACT

Background: Lumbar spine range of motion (ROM) is a key component of injury prevention and normative data has not currently been determined for an elite gymnastics population. In current clinical practice, it is commonplace to measure sagittal spinal alignment, during 'high-load, low-dynamic' control tasks, subjectively, while also only considering the lumbar spine as a single segment

Purpose: To develop normative data for total lumbar spine ROM and ROM during a simulated landing task (SLT) in an elite gymnastics population, evaluating findings in the context of the existing biomechanical literature.

Study Design: Repeated measures, cross sectional design

Methods: Lumbar spine and low lumbar spine (LLS) ROM during a SLT were measured, using the Dorsa Vi: Vi Perform™ system in asymptomatic male and female elite gymnasts. Values for maximal ROM and LLS angle during the SLT were collated and descriptively analyzed. Lumbar ROM and posture was evaluated in relation to the current biomechanical literature and a proposed Conceptual Compressive Lumbar Load Distribution Model (CCLLDM).

Results: Thirty elite gymnasts (15 male, 15 female), participated. Participants were members of the British Artistic Gymnastics elite senior and junior training program and were between the ages of 16 to 30 years. Mean (SD) maximal lumbar spinal movements were 64.23° (6.34°) for flexion and 25.89° (11.14°) for extension. During the SLT, participants performed lumbar spine flexion of 15.96° (8.80°), when considered as a single segment. When considering the lumbar spine as a two segment model the LLS position during the SLT was towards end range anterior pelvic tilt, suggesting LLS extension.

Conclusion: These data provide a baseline for asymptomatic lumbar spine movements in an elite gymnastics population and provides insight into upper and lower lumbar spine movement during a SLT. The data and newly developed CCLLDM provide clinicians with a potential framework to identify sporting skills that may be associated with increased spinal tissue load.

Levels of Evidence: 3b

Keywords: Gymnastics, normative data, range of motion, spinal neutral

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INTRODUCTION

Globally, low back pain (LBP) is associated with significant activity modification and individual burden, resulting in more years affected due to disability than any other condition.[1] LBP contributes up to 30% of total reported athletic injuries. This may lead to a loss of training time and ultimately, may impact competitive performance. Time loss injury incidence is influenced by sport specific demands, with the increased risk of LBP in sports with repeated hyper-extension and rotation movements.[2] Gymnasts are at particular risk, with spinal injury prevalence ranging 25-85%.[3] Landing in gymnastics results in significant ground reaction forces, up to 13 times bodyweight[4] and has been linked to spinal tissue pathology.[5] Common sites of spinal injury include the apophyseal joints, intervertebral discs, and the pars interarticularis.[6]

Awareness of total lumbar spine range of motion (ROM) and sagittal alignment are considered key components in the identification, management and rehabilitation of lumbar spine pathology.[6,7] Gender specific lumbar spine ROM normative data have been published for heathy participants aged 16-90 years, including subjects with varied levels of physical activity.[8] Although these data provide a broad overview of total lumbar spine ROM and highlight the impact of arthrogenic, myogenic and discogenic degeneration on ROM, the heterogeneity of the data provides little insight when extrapolating findings to elite physically active populations. To improve LBP prevention and rehabilitation strategies in an elite gymnastics population, normative data in this physically active subgroup is required[7.]

Although several systems have an ability to measure lumbar spine ROM, limitations exist. Limitations include skin movement errors, variable reliability and validity, and the inability to analyze and collect data wirelessly.[9] X-ray and fluoroscopy are considered the 'gold standard' for assessing lumbar spine ROM, however, repeated radiation exposure has documented risks.[10] The Dorsa Vi: Vi Perform™ enables measurement of lumbar sagittal, frontal and transverse planes of movement through wearable wireless accelerometers, and thus during unrestricted functional and sporting activities.[9]

Awareness and reduction of compressive load distribution, maximal and cumulative end range spinal movements, have been proposed to reduce tissue damage and in turn, lumbar spine time loss injuries.[11] In order to optimize the distribution of axial compressive load through spinal structures during a 'high-load, low-dynamic' control task such as a gymnastics landing, the principle of neutral spine positioning is advocated.[11] Alternatively, optimal spinal posture has been suggested to be '*an envelope of motion and loading associated with optimal tissue health (p97)*'[11] or neutral zone of movement away from end range, not a fixed neutral position.[13,14] Additionally, considering the lumbar spine as a single segment (T12-S2) during functional tasks has been shown to be inadequate and not reflective of full lumbar spine kinematics.[15] In order to assess lumbar spine posture during a 'high-load, low-dynamic' controlled gymnastics landing task, the lumbar spine must be considered as a minimum of two segments.[15-17] Differing contributions of ROM from the upper (T12-L3) and lower (L3-S2) lumbar spine segments have been demonstrated during the activities of sit to stand[15] and drop jump landing.[4] In order to consider the lumbar spine as two segments,[15] low lumbar spine (LLS) maximal movement is driven by anterior and posterior pelvic tilt[18] and parameters for the 'envelope of motion' for the LLS must be established.

The evident gap between current clinical practice and existing literature, presents challenges when managing risk and rehabilitating lumbar spine pathology in elite athletes. Limited research has investigated frontal plane postural changes, as movement in this plane rarely occurs in isolation.[12] The sagittal lumbar spine position associated with optimal compressive load distribution is not well defined in the current literature and the neutral spine position is currently guided by clinical subjective opionion.[11] Although an '*envelope*' of spinal movement has been suggested with regards to optimal compressive lumbar load distribution[11] in vivo, evidence based movement parameters have not been applied to this statement. Currently lumbar spine sagittal alignment and the parameters to the '*envelope of motion and loading*'[11] are considered independently and require a synergistic approach.

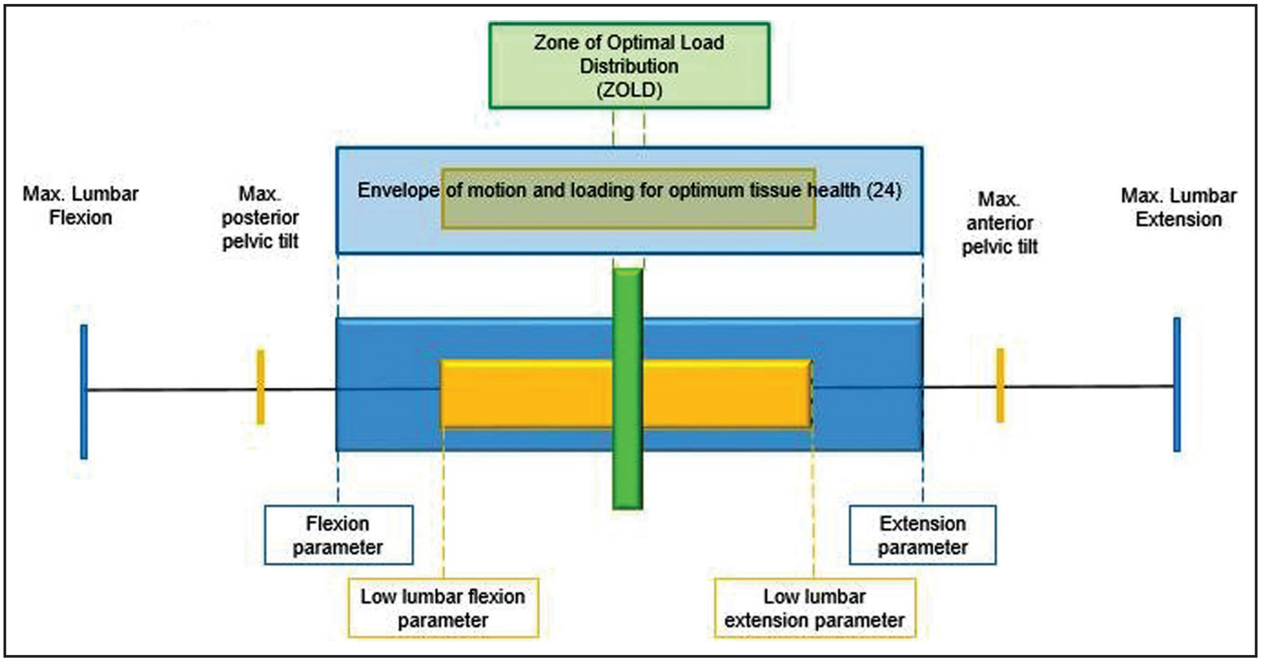

Figure 1. *The Conceptual Compressive Lumbar Load Distribution Model (CCLLDM).*

Therefore a new model, The Conceptual Compressive Lumbar Load Distribution Model (CCLLDM) (Figure 1) is presented. This model provides evidence based parameters to describe the '*envelope of motion*'[11] and establishes an optimum spinal posture, determined by axial compressive load distribution.

The model presented is structured around a zone of sagittal spine alignment associated with optimal load distribution (ZOLD), defined as even axial load distribution through the anterior and posterior lumbar spinal segment. The authors' hypothesize the ZOLD is between 0-2˚ of flexion per segment level.[19-21]

A reduced degree of segmental flexion results in increased load cycles tolerated by spinal tissue before failure.[22] The maximal lumbar flexion parameter is defined as 80% of maximal flexion range, as this position has been shown to optimally tension the lumbodorsal fascia, reducing peak intervertebral disc and ligament load exposure.[12] Spinal segment extension results in increased posterior neural arch loading as the disc is stress shielded.[12,19] Capsular ligament loading occurs at 4˚ of extension per segment level, which combined with increased extensor muscle activation, may be linked to myogenic fatigue.[12,20] Therefore erect standing sagittal alignment, shown to increase lumbar lordosis by 2˚ of extension per segment level, is defined as the extension parameter limit.

Currently no normative data exists regarding total and lumbar spine movement during a SLT, associated with high ground reaction forces,[4] in an elite gymnastics population. The neutral spine position is determined subjectively and considered independently to the '*envelope of motion'* associated with optimal tissue health. The primary purpose of this study was to develop normative data of total lumbar spine ROM, and total LLS ROM during a SLT in an elite gymnastics population. The secondary goal was to evaluate the findings in the context of the proposed CCLLDM.

METHODS

Design

A repeated measures, cross sectional study was conducted in a sample of 30 asymptomatic, world class and professional, elite gymnasts. Data collection was completed, in performance gymnasium by an experienced sports physiotherapist. Data were collected over nine days between training sessions.

Sample

Thirty elite gymnasts (15 male, 15 female), were approached and consented to participate. Participants were members of the British Artistic Gymnastics elite senior and junior training program and were between the ages of 16 to 30 years. Participants were excluded if they had a previous history of spinal surgery, lower limb pathology preventing study protocol completion, were pregnant or less than than six months post-partum, had inflammatory or neurological conditions, undiagnosed pain conditions, implanted electronic devices or a current or previous (within the prior six months) episode of back pain, resulting in a time loss injury, which was defined as missing a scheduled session.[24]

Ethics statement

All participants were provided with a Participant Information Sheet detailing the study purpose, participation requirements, and right to withdraw. All participants provided written informed consent. Participants aged <18 years old were required to have a parent/guardian co-sign the consent form.[25] Permission to access the elite gymnastics population was afforded by British Gymnastics and the English Institute of Sport. Ethical approval was obtained from the University of Birmingham (Ref: 24_02_15_SW).

Apparatus

The Dorsa Vi: Vi Perform™ (dorsaVi, Docklands, Victoria, Australia) measurement system consists of an upper and lower sensor with two tri-axial accelerometers and two single axis gyroscopes. It was placed on the skin using latex free, disposable adhesive application as per the system protocol.[9,26] The reader is directed to Ronichi et al[9] and Charry et al[26] for further information reading the Dorsa Vi: Vi Perform™ system protocol.

The Dorsa Vi system has previously demonstrated excellent inter- and intra-tester reliability for lumbar flexion (ICC $_{2.1}$; 95% CI 0.95 inter-tester, 0.99 intra-tester) and lumbar extension (ICC $_{2.1}$; 95% CI 0.94 inter-tester, 0.98 intra-tester).[9] Concurrent validity has been examined with the NDI Optotrack system.[9] Caution must however be used secondary to potential funding and reporting biases as this evidence is provided by the current Dorsa Vi CEO and senior analyst and has not been published in the peer reviewed literature.[9,26] Another independent and adequately powered evaluation of The Dorsa Vi system was conducted by Laird,[27] further demonstrating excellent inter- and intra-tester reliability for lumbar flexion (ICC $_{2.2}$; 95% CI 0.80 inter-tester, 0.86 intra-tester) and lumbar extension (ICC $_{2.2}$; 95% CI 0.91 inter-tester, 0.79 intra-tester).[27] The use of the Dorsa Vi: Vi Perform™ was therefore supported for use by a single rater in this study.

Procedure:

Participants were required to have risen from bed >three hours prior to participation, to ensure resolution of morning stiffness.[28] Height and weight were measured as part of the the Dorsa Vi: Vi Perform™ system protocol. Participants were instructed to stand with feet shoulder width apart with shoulders flexed to horizontal in the sagittal plane. A visual target was placed 1.5 meters away to standardize head posture, as downward gaze during a squat has been shown to increase hip and trunk flexion.[29] To complete the SLT (due to reduced apparatus accuracy at speed) participants were asked to squat to a position of 90° knee flexion[17] to simulate soft landing technique, associated with reduced peak ground reaction force.[30] A hand held goniometer was used to measure knee flexion by the lead author, following a standardized protocol.[31] This method has demonstrated high intra-tester reliability (ICC 0.85-0.99) and high validity (ICC 0.98-0.99).[31] A height adjustable fitness aerobic step was used as a reference point for SLT repetitions in order to standardize depth. To ensure participants did not sit on the aerobic step, defined by Akerblom[32] as weight bearing through the ischial tuberosities, a set of electronic scales were placed on the step. During the performance of the SLT participants were instructed to make contact with the electronic scales to an upper limit of 20% of sitting body weight. Participants then completed a standardized warm up of five movements into end range lumbar flexion and extension, anterior and posterior pelvic tilt[21,33] to avoid serial effects[11] and stabilize mobility performance.[34]

The Dorsa Vi: Vi Perform™ system was placed on the participants (as previously described) and machine calibration was completed in erect standing, with standing resting lumbar lordosis angle recorded. Participants were instructed to complete a single movement into maximal lumbar flexion, lumbar extension, maximal anterior and posterior pelvic tilt, and into the simulated landing position.

Maximal Lumbar Flexion:
Participants sat on the floor with a foam roller placed under their knees, to reduce hamstring influence on the pelvis and sagittal spine orientation.[35] In this position, the participant's pelvis was placed into maximal posterior pelvic tilt,[15-16] and instructions to maximally flex forward into a pike position in reaching for the toes, were then given to achieve end range[21] (Figure 2a).

Maximal Lumbar Extension:
In the prone 'cobra' position, participants were instructed to maintain iliac spine position, horizontal with the floor and to maximally extend the lumbar spine.[33] Maximal thoracic extension and cervical extension were required to ensure maximal lumbar range was achieved, secondary to regional interdependence and varied contribution of ROM from upper and lower lumbar segments[16,36] (Figure 2b).

Simulated Landing Task (SLT):
Finally, subjects performed the SLT using the previously determined set up, making contact with the electronic scales, not exceeding the weight limit. (Figure 2c)

Data management and analysis:
Total lumbar spinal movements were calculated, by the determining the difference between the upper and lower sensor measurements in the sagittal plane.[26] Lumbar flexion in the sagittal plane was indicated by a positive value and lumbar extension a negative value from the calibrated standing position. LLS movements, driven by anterior and posterior pelvic tilt ROM, were taken from the lower sensor measurements. All maximal lumbar spine movements, total lumbar and LLS angles during the SLT were collated and descriptively analyzed using means and standard deviation. Total and LLS posture during the SLT was then considered in relation to The CCLLDM.

RESULTS
Participants were aged 16-29 years with a mean (SD) of 19.73 years (3.51), height 162.1cm (8.4) and weight 60.72kg (8.86). Mean standing lumbar lordosis was -30.80˚ (9.99). Maximal lumbar flexion and extension movements are presented in Table 1.

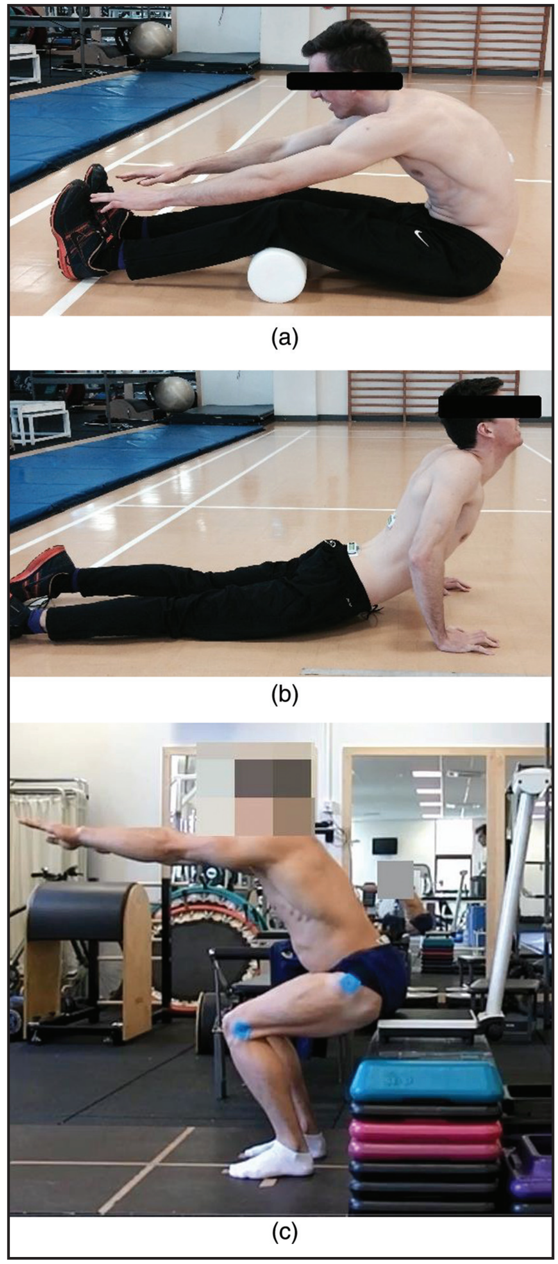

Figure 2. *a) Maximal lumbar flexion, b) Maximal lumbar extension, c) Simulated Landing Task.*

Mean (SD) maximal spinal movements were 64.23˚ (6.34) for lumbar flexion and -25.89˚ (11.14) for extension. During the SLT all participants performed lumbar flexion relative to the calibration position [mean 15.96˚ (8.80)]; considering the lumbar spine as a single segment. In relation to the parameters of motion of the proposed CCLLDM, Figure 3 presents the maximal lumbar spine movements and lumbar movement during the SLT. When considering the lumbar spine as a two segment model the LLS

Table 1. *Lumbar spine movements.*

Posture/Activity	Active ROM (°) (Mean ±SD)	Range (°)
Standing Lumbar Lordosis	-30.80 ± 9.99	-13.00 to -55.00
Flexion	64.23 ± 6.34	53.38 to 77.71
Extension	-25.89 ± 11.14	-6.04 to -55.39
Anterior Pelvic Tilt	39.52 ± 6.52	24.23 to 50.52
Posterior Pelvic Tilt	11.05 ± 9.41	0.84 to 28.03
Lumbar spine as a single segment – simulated landing task	15.96 ± 8.80	1.4 to 34.8
Low lumbar spine (pelvic tilt) – simulated landing task	31.18 ± 6.85	20.31 to 44.37
ROM (Range of Motion)		

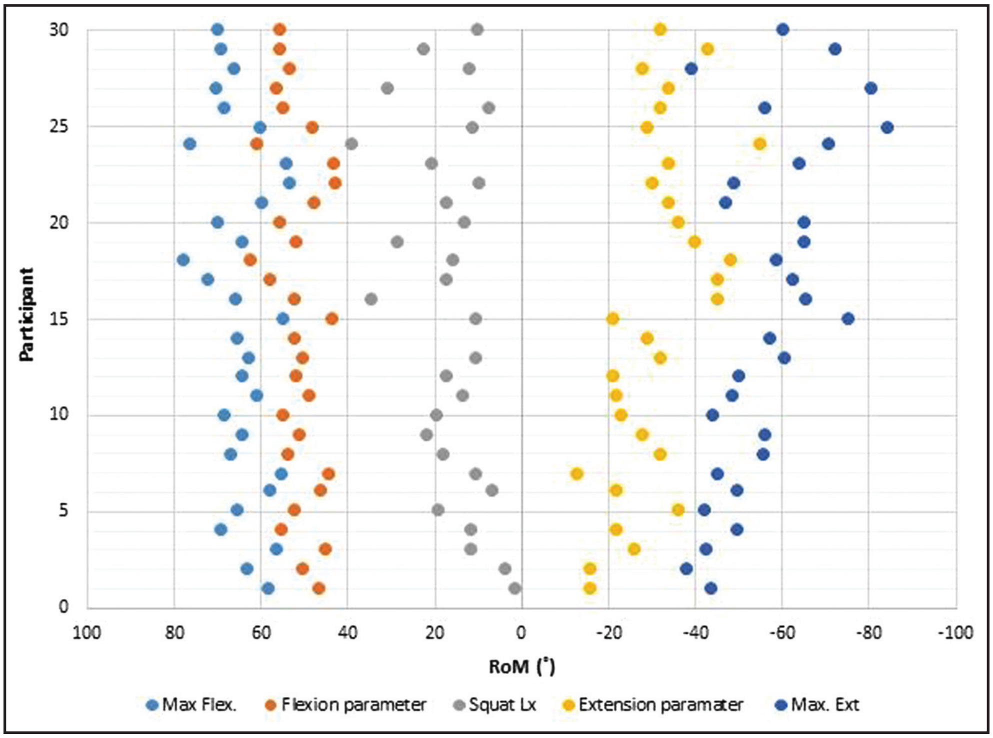

Figure 3. *Maximal lumbar spine movement and lumbar spine position as a single segment during Simulated Landing Task (SLT), in relation to CCLLDM.*

mean values for maximal posterior pelvic tilt were 11.05˚ (9.41) and for anterior pelvic tilt were 39.52˚ (6.52). Mean values for LLS movement (i.e. pelvic tilt relative to the standing calibration position) were 31.18˚ (6.85). Data were missing for participant 14 secondary to apparatus error however the total ROM is presented.

DISCUSSION

This study provides the first normative data set of maximal lumbar spine ROM for an elite gymnastics population. Standing lumbar lordosis and maximal total lumbar spine ROM normative data provide reference values for asymptomatic individuals in this physically active population. The data also provide insight into total lumbar and LLS movement during a 'high-load, low-dynamic' controlled SLT, evaluated in the context of the newly proposed CCLLDM.

Mean maximal lumbar flexion (64.23˚) and lumbar extension (-25.89˚) ROM values were consistent with previous literature as measured with the CA6000 Spine Motion Analyzer and Epionics SPINE system.[8,37] Troke et al[8] reported median maximal lumbar flexion ROM values of 73˚ and 68˚ in males and females respectively (measured in a standing position), in a sample of 405 asymptomatic individuals aged 16-90 years. Dreischarf et al,[37] completing maximal lumbar flexion and lumbar extension movements in standing with knees extended, also demonstrated similar results with a sample of 115 participants, aged 20-29 years achieving mean values of 53.7˚ for maximal lumbar flexion and -31.1˚ for lumbar extension. Performing maximal movement measurement protocols in standing versus sitting and the greater lumbar spine ROM requirements for an elite gymnastics subgroup, may explain the increased mean maximal lumbar flexion ROM in the current study. As lumbar spine mobility has shown to reduce with increasing age, the broad age range and limited elite gymnastics population size, may also reflect the variance in maximal total lumbar spine ROM.[8] Standing lumbar lordosis angles presented in the current study (-30.80˚) are also consistent with previous literature with mean lumbar lordosis of 36.4˚ demonstrated by Dreischarf et al[22] and 38.9˚ by Mitchell et al[17] in a sample of 107 nursing students with a mean age of 21 years.

The current findings demonstrate that participants performed the SLT with the pelvis close to maximal anterior pelvic tilt range, suggesting LLS extension. LLS extension during a 'high-load, low-dynamic' control task may result in increased posterior neural arch load,[19] which may be associated with vertebral pathology, highly prevalent in the gymnastic population.[3,6] This is further supported by Mitchell et al[17] who demonstrated participants performing LLS extension relative to the calibrated standing position during a stand to squat task. Wade et al[4] measured lumbar spine posture during a drop jump landing from one meter, in twenty one female gymnasts (mean age ±SD = 13 ±3 years). The mean lower lumbar spine position is extension, with the upper lumbar spine in flexion 0.1 seconds before and after the landing tasks. LLS extension would not have been evident when considering the spine as a single segment, further supporting the suggestion from the current study that considering the lumbar spine as a single segment does not reflect variation between upper and lower lumbar spine kinematics during a low dynamic control SLT.[15]

The CCLLDM presents measures for the 'envelope of motion'[11] associated with proposed optimal lumbar spine posture and compressive axial load distribution, during 'high-load, low-dynamic' control tasks. Establishing measures for the 'envelope of motion'[11] enables identification of high risk lumbar spine postures, associated with increased spinal tissue load. The CCLLDM provides a framework for clinicians to identify sporting tasks associated increased spinal tissue axial load, facilitating load management strategies, with the aim of reducing time loss injury.[38] With improved awareness of higher risk 'low-dynamic' control tasks, clinicians may be able to provide coaches with information regarding the cumulative biomechanical consequences of performing high-repetition sporting skills associated with increased spinal loads.

Limitations

A potential limitation is that data collection took place following a morning training session. Although the impact from viscoelastic hysteresis on lumbar spine ROM has been well demonstrated,[12,39] as participants were part of the British Gymnastics program building towards The Olympic Games, morning activities could not be controlled for each participant. Lumbar spine compressive load biomechanics is grounded in single segment, cadaveric literature.[7,12,15] Caution must therefore be used when transferring the results of this research to young, asymptomatic subjects.[12] LLS, pelvic driven movement, occurring during the SLT reflects current research regarding lumbar spine kinematics[4] however, transferability of results is limited as the pelvic tilt data presented is in relation to the lower sensor calibration position and does not provide a true reflection of relative movement into lumbar flexion, extension and pelvic tilt. Standardized positioning, as per the methods achieved in the current study, is therefore vital to ensure comparable data of maximal range to LLS position during the SLT. Clinicians should therefore consider pelvic driven data in relation to maximal anterior and posterior pelvic driven ROM, when implementing the described methodology.

CONCLUSIONS

The results of the current study provide the first normative data set for lumbar spine ROM for an elite asymptomatic gymnastics population. These data will provide clinicians with reference values when developing rehabilitation programs following lumbar spine pathology. Lumbar spine posture during the SLTs further supports the importance of considering the lumbar spine as a minimum of two segments and provides analysis of posture during a simulated sporting task which may be associated with increased spinal tissue load. The CCLLDM has been developed for clinicians, synthesizing biomechanical literature investigating the impact of compressive axial lumbar load distribution on spinal tissues. The CCLLDM provides a model for clinicians to consider when developing rehabilitation programs and establishes a framework for identifying sporting activities associated with higher risk lumbar spine postures. Future studies should aim to identify sport specific tasks associated with end of range spinal positions. The CCLLDM requires further implementation and targeted research in varying sports to assess transferability. These data may ultimately enhance the ability of clinicians to develop lumbar spine injury prevention, rehabilitation, and load management strategies in the elite sporting population.

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